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Assessment and Spatial distribution of zinc pollution in agricultural soils of Chaoyang, China

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Abstract

In this paper, we collected 295 soil samples from Chaoyang as the experiment material, then identify the concentration and spatial distribution of zinc (Zn) in agricultural soils on the basis of The integrated pollution index (IPI) and index geoaccumulation (I_{geo}). The concentration of Zn in soils of Chaoyang are from 22.787 to 669.597 mg kg^{-1},with an average concentration of 107.082 mg·kg^{-1}. And results of the evaluation show that the pollution excess rate is 2.03%, which indicated that most of samples are slightly polluted. Compared two evaluation methods, integrated pollution index focuses on the evaluation of pollution results, the Geo accumulation index method is more accurate and objective.

Keywords: Zinc(Zn); IPI; I_{geo}; Agricultural soil; Chaoyang City

1. Introduction

Human activities have been causing noteworthy increases contents of trace metals to the environment, particularly during the industrial period [1]. Soils may be polluted with heavy metal due to industrial processes, application of sewage sludge, fertilisers and atmospheric deposition. Zinc occurs in natural soils as a result of weathering of the soil parent material, and total Zn contents in soils in average ranges from 40 to 120 mg·kg^{-1} depending on their lithology [2]. Because Zn is an essential nutrient for plants and soils are often deficient in it [3], the Zn content of farmland soils is usually higher than that of natural soils mainly due to the addition of commercial fertilisers, liming materials or manures [4]. In addition, fungicides and pesticides containing Zn also contribute to its presence in agricultural soils [5]. Zn can

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accumulate in agricultural soils, achieving values considerably higher than its optimum concentration as a nutrient, and it may be toxic to soil organisms.

Heavy metal contamination of soils is widespread and there is a risk of transfer of toxic and available metals to humans, animals, and agricultural crops. In fact, heavy metals have a significant toxicity for humans, animals, microorganisms and plants [6, 7].

Although trace metal pollution has been extensively studied in the eastern coastal/industrial regions of China [8, 9, 10, 11], little is known about the trace metal pollution in the northwest farmland areas of China. Chaoyang City is the main oil crops and the grains main producing areas of Liaoning Province.

Geographic information system is a computer system which is used widely in different fields,for inputting, storaging, querying, analyzing and displaying a large number of geographic data [12].There are lots of researches in the field of environmental assessment carried out based on GIS [13, 14, 15, 16 , 17]. Index of Geoaccumulation (*Igeo*) which was advanced by German scientist Muller in 1969 presents quantitative indicator in the study of heavy metal pollution of water sediments. Recently , it is widely used to evaluate the heavy metal pollution [18,19,20,21].

According to "Environmental quality standards for soils"(GB 15618-1995), this paper evaluates the Zn pollution state in agricultural soils of Chaoyang City in China with integrated pollution index,and studies the characteristics of the spatial variation about zinc pollution in agricultural soils of Chaoyang City based on GIS technology.

2. Materials and methods

2.1. Sampling and Analysis

In order to obtain representative samples, this study collected 295 agricultural surface soil samples (0-20 cm) with grid method from five districts which are Chaoyang County, Jianping County, Kazuo County, Beipiao City and Lingyuan City, Chaoyang City in Liaoning Province, China by the GPS. Each sample consisted of 10 points ,and we took the same weight of 100g per point , then the weight of a soil sample was mixed to 2 kg. Soil samples were air-dried and passed a plastic sieve of 100 mesh .Distribution of sampling sites was shown in Fig. 1.

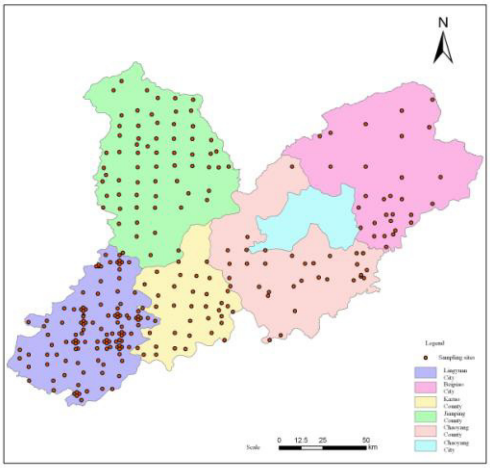

Fig. 1. Distribution of sampling sites in the soil.

Physical and chemical properties of soil samples were analyzed by soil agricultural chemistry analysis methods. Total zinc was measured with a flame atomic absorption spectrometer.

2.2. Statistical evaluation

The statistical analysis were completed by EXCEL 2003 and graphics were completed by ARCGIS 9.3.

2.3. Evaluation standard and methods

2.3.1. The integrated pollution index method

The evaluation standard used in this paper includes the upper limit of soil environmental background value in Liaoning Province and "Environmental quality standards for soils" (GB 15618-1995). The integrated pollution index is used commonly as a evaluation method at home and abroad, which includes the single factor index and Nemerow integrated index.

（1）The single factor index is calculated as:

$$P_i=C_i/S_i \tag{1}$$

where, define P_i as the single pollution index of the heavy metal, C_i as the measured concentration of the heavy metal (mg·kg^{-1}), S_i as the value of the evaluation criteria of the heavy metal (mg·kg^{-1}, this study is 0.6 mg·kg^{-1}). When $P_i \leq 1$, the soil is clean; if $P_i > 1$, the soil is polluted by heavy metal. The greater Pi, the more serious pollution.

(2)Nemerow integrated pollution index is calculated as:

$$P_N=\sqrt{\frac{P^2{}_{iave}+P^2{}_{i\max}}{2}} \tag{2}$$

where, Piave and Pimax are the average pollution index and the largest single pollution index respectively. Define $P_N \leq 0.7$ as clean, $0.7 < P_N \leq 1$ as still clean(Warning limit),$1<P_N \leq 2$ as slight pollution,$2< P_N \leq 3$ as middle pollution, $P_N >3$ as heavy pollution .

2.3.2. The Geoaccumulation index method

It is especially widely used for evaluation of heavy metal pollution in the study of modern sediments, and is calculated as:

$$I_{geo}=\log_2^{[C_i/(K\times B_i)]} \tag{3}$$

where, C_i is the concentration of the heavy metal in the soil (mg·kg^{-1}), K is a constant , represents the changes of background value which might be caused by rock movement(general value is 1.5). B_i is the geochemical background concentration of the heavy metal in the soil (mg·kg^{-1}). B_i value determines I_{geo}, different B_i values will result in a greater difference , in this study B_i =0.11 mg kg^{-1} [22]. According to I_{geo} values, the pollution has distinguished seven classes, from Class 0 (≤0) to Class 6 (I_{geo} >5)[23], class 0 to 5, indicate pollution levels from none to very strong, the element content of the highest class 6 may reach hundreds of times than the background value.The specific classification is shown in Table 1.

Table 1. I_{geo} and classification of pollution degree.

I_{geo}	Class	Pollution degree
≤0	0	Clean
0-1	1	Slight pollution
1-2	2	Middle pollution
2-3	3	Mid-strongly pollution
3-4	4	Strongly pollution
4-5	5	Strongly-extremely pollution
>5	6	Extremely pollution

3. Results and analysis

3.1. The content of Zn in the soil

The Zn content in Chaoyang city generally shows upward trend but leveling off gradually (Fig. 2, Table 2).With the result we know the distribution has been rather dispersed, and the variation coefficient is more than 65%. Parts of Zn distribution zones seem significantly different, which is likely owing to the presence of Zn pollution. The Zn content of agricultural soils in Chaoyang City range from 22.787 $mg \cdot kg^{-1}$ (Jianping County) to 669.597 mg kg^{-1} (Kazuo County) , and the mean Zn is 107.082 $mg \cdot kg^{-1}$. The maximum value which has been greater than the secondary standard value (300 $mg \cdot kg^{-1}$) of “Environmental quality standards for soils”(GB 15618-1995), is much more 10 times than the background value (60 $mg \cdot kg^{-1}$)[24], which indicates that Zn accumulation state in the soil is apparent.

Table 2. The concentration of Zn in the soil.

Area	Count	Min. ($mg \cdot kg^{-1}$)	Max. ($mg \cdot kg^{-1}$)	Mean ($mg \cdot kg^{-1}$)	S.D.	CV[%]	Skewness	Kurtosis
Chaoyang County	31	28.149	274.087	85.497	56.989	66.656	0.693	1.184
Jianping County	65	22.787	627.489	91.478	101.030	110.442	3.185	11.861
Kazuo County	37	33.214	669.597	94.913	112.486	118.515	3.816	15.868
Beipiao City	29	29.612	573.922	144.955	136.327	94.048	1.761	2.429
Lingyuan City	133	38.877	509.545	114.866	83.820	72.972	2.454	6.660
Total	295	22.787	669.597	107.082	96.528	90.144	2.920	9.616

3.2. Analysis of integrated pollution index

The evaluation results of integrated pollution index (P_N) are shown in Table 3. According to “environmental quality standards for soils”(GB 15618-1995) ,there are 6 exceeded points(Kazuo County 3,Jianping County 1，Beipiao Cit 1，Lingyuan Cit 1),and the exceeded rate is 2.03%，the highest one is Kazuo County,8.1%.In the five regions, only Chaoyang County has not been polluted.Based on the classification of pollution degree,The total P_N is 1.598, which indicates that the pollution degree is slight pollution.The order of pollution degree of Chaoyang City is as follows, Kazuo County > Jianping County> Beipiao City> Lingyuan City> Chaoyang County.

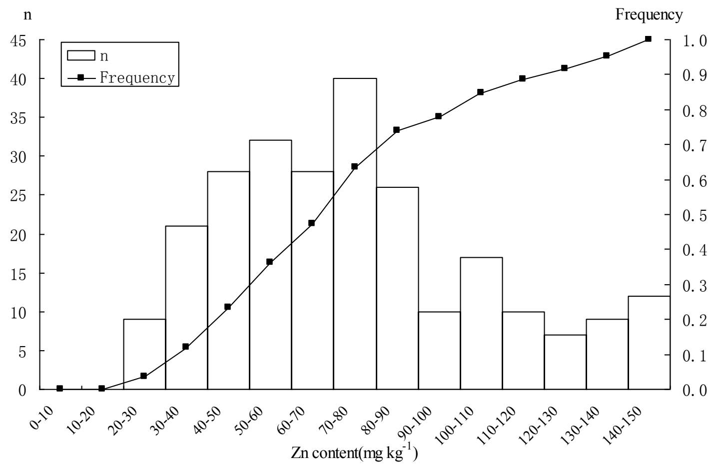

Fig. 2. Frequency distribution of Zn in the soil.

Table 3. The pollution index of Zn in the soil .

Area	Monitoring sites	Excess sites	P_i Min.	P_i Mean	P_i Max.	P_N	Pollution degree
Chaoyang County	31	0	0.094	0.285	0.914	0.677	Still clean
Jianping County	65	1	0.076	0.305	2.092	1.495	Slight pollution
Kazuo County	37	3	0.111	0.316	2.232	1.594	Slight pollution
Beipiao City	29	1	0.099	0.483	1.913	1.395	Slight pollution
Lingyuan City	133	1	0.130	0.383	1.698	1.231	Slight pollution
Total	295	6	0.076	0.357	2.232	1.598	Slight pollution

3.3. Analysis of Igeo

The results of I_{geo} are shown in Table 4. The average I_{geo} of Chaoyang City is -0.19 which represents class 0(still clean). Among the 295 samples,184 samples belong to class 1,73 samples belong to class 2,29 samples belong to class 2,and 9 samples belong to class 3.Anyway the other regions belong to clean level, in addition to a number of monitoring points in Beipiao City and Lingyuan City.

3.4. Comparative analysis of two evaluation methods

There is a difference between the results of the two evaluation methods, integrated pollution index method showing a slight pollution while the Igeo method indicates clean. Two factors may contribute to the discrepancy. (1) Different standard values：the former is sensitive to pH, the latter more to geochemical background value; (2) Different emphatic points: diverse factors have impact on the Zn concentration assessment involving soil organic matter, soil texture, soil Eh. Other factors such as human activity like fertilization and vehicle emission may also have influences on Zn pollution situation.

The pollution measurement shows clean though there is no excess sampling resources and PN is 0.67. We speculate that the largest single pollution index is overemphasized, thus leading to a distorted assessment result. One way to solve the problem is to give average pollution index larger weight.

Table 4. The classification of Zn pollution based on Igeo in the soil .

Area	I_{geo}			Pollution degree	number						
	Mean	Min.	Max.		class 0	class 1	class 2	class 3	class 4	class 5	class 6
Chaoyang County	-0.30	-1.68	1.61	Still clean	21	8	2	0	0	0	0
Jianping County	-0.45	-1.98	2.80	Still clean	48	10	5	2	0	0	0
Kazuo County	-0.34	-1.44	2.90	Still clean	28	6	2	1	0	0	0
Beipiao City	0.22	-1.60	2.67	Slight pollution	14	8	5	2	0	0	0
Lingyuan City	0.05	-1.21	2.50	Slight pollution	73	41	15	4	0	0	0
Total	-0.19	-1.98	2.90	Still clean	184	73	29	9	0	0	0

4. Conclusions

Zn concentration of soils taken from Chaoyang has an average value of 107.082 mg·kg^{-1}, fluctuating from 22.787 to 669.597 mg·kg^{-1}. The result is higher than the background value. The spatial distribution of Zn is more dispersed and pollution excess rate is 2.03%. On the whole, the pollution is quite slight and the soil environment quality is good. However, improper fertilization and irrigation from the past may cause Zn accumulation in some of the areas. Considering the different results adopting the two different methods, we should set a criteria that can reflex the results more accurately. In this assay, the geoaccumulation index method is more sensitive and objective than integrated pollution index.

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